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RESEARCH MEMORANDUM

AERODYNAMIC CHARACTERISTICS AT SMALL SCALE AND A MACH NUMBER OF 1.38 OF UNTAPERED WINGS HAVING M AND W PLAN FORMS

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NATIONAL ADVISORY COMMITTEE
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AERODYNAMIC CHARACTERISTICS AT SMALL SCALE AND A MACH NUMBER OF 1.38 OF UNTAPERED WINGS HAVING M AND W PLAN FORMS

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SUMMARY

An investigation was made at a Mach number of 1.38 and a Reynolds number of 390,000 to determine the supersonic aerodynamic characteristics of several wings having M and W plan forms. The wings had panel sweep angles of 60° and NACA 65A006 airfoil sections and were untapered. The basic aspect ratio was 4, but several tip plan-form modifications which increased the aspect ratio were examined. The results are compared with approximately equivalent results for sweptback wings. The wings were tested as semispan models mounted from the tunnel wall with no provision made for removing the tunnel boundary layer. The test results, therefore, were undoubtedly influenced by interaction of the models with the tunnel boundary layer.

Alterations of wing-tip plan form caused significant changes in the characteristics of the W-wing but seem to have changed only the localized tip loading of the M-wing. The M-wings experienced higher lift-curve slopes than the W-wings but values of maximum lift-drag ratio were comparable for the two types of plan form and fell between those of the 45° and 60° sweptback wings. Values of lift-curve slope and minimum drag coefficient for the M plan forms were about equal to those of the rigid 60° sweptback wing. The serious pitching-moment nonlinearities observed with the 60° swept wing were considerably reduced by use of the M plan form and were essentially eliminated with the W plan form.

INTRODUCTION

The use of wings having M or W plan forms has been proposed as one possible method of obtaining the drag benefits of sweepback at transonic speeds without the undesirable stability characteristics frequently encountered at high lift coefficients on highly sweptback wings. Experiments reported in reference 1 indicated that at transonic speeds much of

the drag effect of sweepback was realized by M- and W-wings and the aerodynamic-center movements in the transonic range were much less severe than for the conventional sweptback wing. Certain structural and aeroelastic benefits of M- and W-wings are also discussed in reference 1. A low-speed stability investigation of a model having a W-wing (ref. 2) indicated stability characteristics superior to those of a corresponding sweptback wing. The use of M- and W-wings on a complete model having various tail locations has been investigated at high subsonic speeds and reported in reference 3.

The supersonic characteristics of M and W wing plan forms have been essentially neglected except for the determination of zero-lift drag at Mach numbers up to 1.4, reported in reference 4. The purpose of the investigation reported herein was to provide more complete longitudinal characteristics of M- and W-wings at a low supersonic speed. As a part of this investigation, the effects of several tip plan-form modifications to these wings were determined.

The tests reported in the present paper were made during the summer of 1950 but the results were not published because of their small scale (Reynolds number of 390,000) and because they were undoubtedly influenced by interaction of the model with the tunnel boundary layer. Inasmuch as no other results on lifting characteristics of M- and W-wings at supersonic speeds have become available, the small-scale results are published at this time.

COEFFICIENTS AND SYMBOLS

C_L lift coefficient, $\frac{\text{Lift}}{qS/2}$

C_D drag coefficient, $\frac{\text{Drag}}{qS/2}$

ΔC_D drag coefficient due to lift

C_m pitching-moment coefficient about $0.25\bar{c}$, $\frac{\text{Pitching moment}}{q\frac{S}{2}\bar{c}}$

C_B bending-moment coefficient about root chord, $\frac{\text{Bending moment}}{q\frac{S}{2}\frac{b}{2}}$

q dynamic pressure, $\frac{\rho V^2}{2}$, lb/sq ft

S twice area of semispan model, sq ft

$\bar{c}$ mean aerodynamic chord of wing, $\frac{2}{S}\int_0^{b/2} c^2 dy$, ft

c local wing chord, ft

b twice span of semispan model, ft

y lateral distance from root, ft

ρ air density, slugs/cu ft

V airspeed, fps

α angle of attack, deg

y_{cp} lateral center-of-pressure location, fraction of semispan, C_B/C_L

y_{ca} lateral distance to centroid of area, $\frac{4}{Sb}\int_0^{b/2} cy\,dy$, fraction of semispan

L/D ratio of lift to drag

$C_{L_\alpha} = \frac{\partial C_L}{\partial \alpha}$

MODELS AND APPARATUS

Drawings of the semispan wings of M and W plan form are given in figures 1(a) and 1(b), respectively. One wing of M plan form and one of W plan form were constructed of solid steel for this investigation. Each wing was made originally with the longest tip shown for that wing in figure 1. The tip airfoil sections were similar to those of the main wing. During the test program, the tips were cut back successively and tests were made with each of the other tip plan forms shown in figure 1. Each wing and tip configuration was tested with smooth leading edge and with very fine-grain roughness applied to the forward 10-percent chord on upper and lower surfaces.

The models were tested in the Langley 6-inch supersonic tunnel which is described in reference 5. The models were mounted through the tunnel side wall so that the wall served as a reflection plane. The gap around

the wing root was sealed with sponge rubber to prevent air leakage. Aerodynamic forces and moments were measured by a 5-component electrical strain-gage balance. The tunnel air temperature was kept above 180° F during the tests to avoid the effects of moisture condensation in the test section. The resulting test Reynolds number was about 390,000. During the tests, the pressure distribution along the top of the tunnel was observed to insure that the tunnel normal shock remained downstream of the test section.

RESULTS AND DISCUSSION

Effects of tunnel boundary layer.- Inasmuch as the tunnel boundary layer undoubtedly influenced the test results, the possible boundary-layer effects will be discussed briefly before the test results are presented. Measurements have indicated that at the model position the total boundary-layer thickness was about 0.25 inch and the displacement thickness was about 0.035 inch. Although previous experimental studies indicated that good agreement was obtained between tests of semispan triangular wings in this tunnel and full-span triangular wings in other facilities, the possibility remains that the M and W plan forms may interact with the boundary layer in a more serious manner.

In the case of the W-wing the pressure disturbances at the wing root would be propagated forward in the boundary layer and the resulting boundary-layer thickening would create a shock originating on the tunnel wall appreciably ahead of the model root. This shock would cross the outer wing panel well ahead of the Mach line from the root leading edge. Under lifting conditions this shock would be expected to cause changes in both flow direction and velocity and thus would alter the load distribution over the wing.

With the M-wing the tunnel-boundary-layer effects may be even more severe because the boundary layer is acted on by pressure disturbances not only from the wing root but from the entire leading edge of the inboard panel. It is conceivable that the shock from the thickened boundary layer and the shock from the leading edge of the midsemispan juncture may interact to form a choked region ahead of the inboard part of the wing.

Although the magnitudes of the effects of the tunnel boundary layer are not known, the comparison of wing plan forms presented probably illustrates at least qualitatively the relative merits of the plan forms considered. Certain phases of the results such as the effects of the tip extensions on the W-wing are probably nearly unaffected by the tunnel boundary layer.

Basic data.- The basic aerodynamic characteristics of the various wing and tip configurations investigated are presented in figures 2 to 6. Each figure contains results obtained on a given configuration with and without leading-edge roughness. The addition of roughness generally produced an appreciable increase in minimum drag and in some cases an improvement in the linearity of the variation of pitching-moment coefficient with lift coefficient at low values of lift coefficient.

Various aerodynamic parameters determined from the test results are summarized in table I. Slope measurements to determine these parameters were made over a lift-coefficient range from -0.2 to 0.2. Values of $\partial C_m/\partial C_L$ for the smooth-leading-edge cases are not presented because of the departure from linearity which occurred at low lift coefficients for some configurations. Values of $C_{D_{min}}$ and $(L/D)_{max}$ are not presented with leading-edge roughness because of the probability that drag comparisons were compromised by differences in applied roughness.

In the absence of leading-edge suction, the resultant force produced by angle of attack is directed normal to the chord plane. For this case the drag-rise factor $\Delta C_D/C_L{}^2$ would be equal to the reciprocal of the lift-curve slope in radians. The presence of leading-edge suction is therefore indicated by a value of drag-rise factor less than the lift-curve-slope reciprocal. Values of the lift-curve-slope reciprocal are included in table I for comparison with the drag-rise factor.

Effect of tip extensions.- Addition of the tip extension to the M-wing resulted in a movement of the center of pressure rearward relative to the mean aerodynamic chord and outward relative to the centroid of area together with a small increase in lift-curve slope. These effects are particularly noticeable with the rough leading edge. At a Mach number of 1.38 the change in tip plan form should affect the loading only over a small region at the tip of the M-wing. It may be concluded, therefore, that the tip region of the M-wing carried considerably more load with the extended tip than with the streamwise tip.

The M-wing with the streamwise tip and smooth leading edge experienced a drag-rise factor $\Delta C_D/C_L{}^2$ which was noticeably greater than the lift-curve-slope reciprocal in radians. This is probably indicative of the existence of flow separation even in the low lift-coefficient range over which the parameters were measured. Inasmuch as the addition of leading-edge roughness essentially eliminated the effects of the separation, the separation was probably the result of extensive laminar boundary layer and would not be expected to occur at high Reynolds number. For this reason, little significance should be attached to the increase in $(L/D)_{max}$ resulting from addition of the tip extension to the M-wing.

Changes in the tip plan form of the W-wing could produce loading changes over a considerable part of the wing because, at a Mach number of 1.38, the entire outer panel and part of the inner panel lie within the tip Mach cone. The results in table I show that appreciable increases in lift-curve slope were produced by either tip extension on the W-wing. The lateral center of pressure of the W-wing with streamwise tip was well inboard of the centroid of area, but the addition of tip extensions brought these points closer together until they essentially coincided for the longest tip. Both tip extensions produced considerable forward movement of the aerodynamic center.

Appreciable reductions in drag-rise factor were produced by both tip extensions on the W-wing but increases in minimum drag also occurred so that the resulting values of $(L/D)_{max}$ were about equal to or less than that for the wing with streamwise tip.

Comparison of M, W, and swept plan forms.- A comparison of the M and W plan forms shows that the M-wings had considerably higher lift-curve slopes than the W-wings. The lowest minimum drag coefficient was experienced by the W-wing with streamwise tip. Addition of the tip extensions to the W-wing, however, increased the minimum drag coefficient to values greater than those for either M-wing.

Examination of the values of drag-rise factor and lift-curve-slope reciprocal in table I indicates that the W-wing with all tip configurations exhibited appreciable leading-edge suction; whereas the M-wing showed essentially none. For this reason, the values of $(L/D)_{max}$ for the W-wings were comparable to those for the M-wings in spite of the lower lift-curve slopes of the W-wings.

It is of interest to compare the results of the present investigation with the data of reference 5 which presents the characteristics of a series of sweptback wings having the same airfoil sections and tested in the same test facility at the same Mach number as the wings of the present investigation. The sweptback wings had an aspect ratio of 4 and a taper ratio of 0.6.

The 60° sweptback wing had a lift-curve slope uncorrected for flexibility about equal to that of the W-wings with extended tips. When corrected to the rigid condition, the sweptback-wing lift-curve slope became about equal to that of the M-wings. The lift-curve slopes of the M- and W-wings should be much less affected by flexibility than that of the 60° sweptback wing for comparable wing structures. (See ref. 1.)

Before comparing drag characteristics, account should be taken of the end-plate drag included in the sweptback-wing data. As stated in reference 5, the end-plate drag coefficient was 0.002 for the 45° swept wing at zero lift. If this value is assumed to be independent of angle

of attack and sweepback, the corrected values of minimum-drag coefficient become 0.019 and 0.010 for the 45° and 60° swept wings, respectively. Similarly, the corrected values of $(L/D)_{max}$ become 6.3 and 9.6 for the 45° and 60° swept wings, respectively.

The values of $C_{D_{min}}$ given in table I for the M- and W-wings with streamwise tips are about equal to that of the 60° swept wing. Although some increase in minimum drag resulted from addition of the tip extensions, all values of $C_{D_{min}}$ for the M- and W-wings were much less than that of the 45° swept wing. All the values of $(L/D)_{max}$ for the M- and W-wings fell between those of the 45° and 60° swept wings.

Figure 7 presents a comparison of the aerodynamic characteristics of the M- and W-wings with streamwise tips with those of the 60° sweptback wing of reference 5. The comparison is for the smooth-leading-edge condition and no corrections have been applied for flexibility or for the end-plate drag of the sweptback wing. The 60° sweptback wing exhibited severe nonlinearities in the variation of C_m with C_L. These nonlinearities were considerably reduced by use of the M or W plan form and were essentially eliminated with the W plan form with roughened leading edge (figs. 4 to 6), in the range of lift coefficients investigated.

CONCLUDING REMARKS

An investigation was made at a Mach number of 1.38 and a Reynolds number of 390,000 to determine the supersonic aerodynamic characteristics of several wings having M and W plan forms with panel sweep angles of 60°. The results have been compared with approximately equivalent results for sweptback wings. The results were undoubtedly influenced by interaction of the model with the tunnel boundary layer.

Alterations of wing-tip plan form caused significant changes in the characteristics of the W-wing but seem to have changed only the localized tip loading of the M-wing. The M-wings experienced higher lift-curve slopes than the W-wings, but values of maximum lift-drag ratio were comparable for the two types of plan form and fell between those of the 45° and 60° sweptback wings. Values of lift-curve slope and minimum drag coefficient for the M-wing plan forms were about equal to those of the rigid 60° sweptback wing. The serious pitching-moment nonlinearities

observed with the 60° swept wing were considerably reduced by use of the M plan form and were essentially eliminated with the W plan form.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 1, 1954.

REFERENCES

1. Campbell, George S., and Morrison, William D., Jr.: A Small-Scale Investigation of "M" and "W" Wings at Transonic Speeds. NACA RM L50H25a, 1950.

2. Polhamus, Edward C., and Becht, Robert E.: Low-Speed Stability Characteristics of a Complete Model With a Wing of W Plan Form. NACA RM L52A25, 1952.

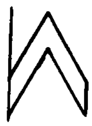
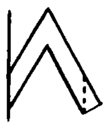
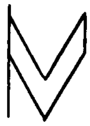
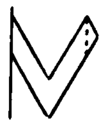
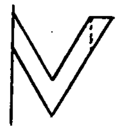
3. Goodson, Kenneth W., and Becht, Robert E.: Wind-Tunnel Investigation at High Subsonic Speeds of the Stability Characteristics of a Complete Model Having Sweptback-, M-, W-, and Cranked-Wing Plan Forms and Several Horizontal-Tail Locations. NACA RM L54C29, 1954.

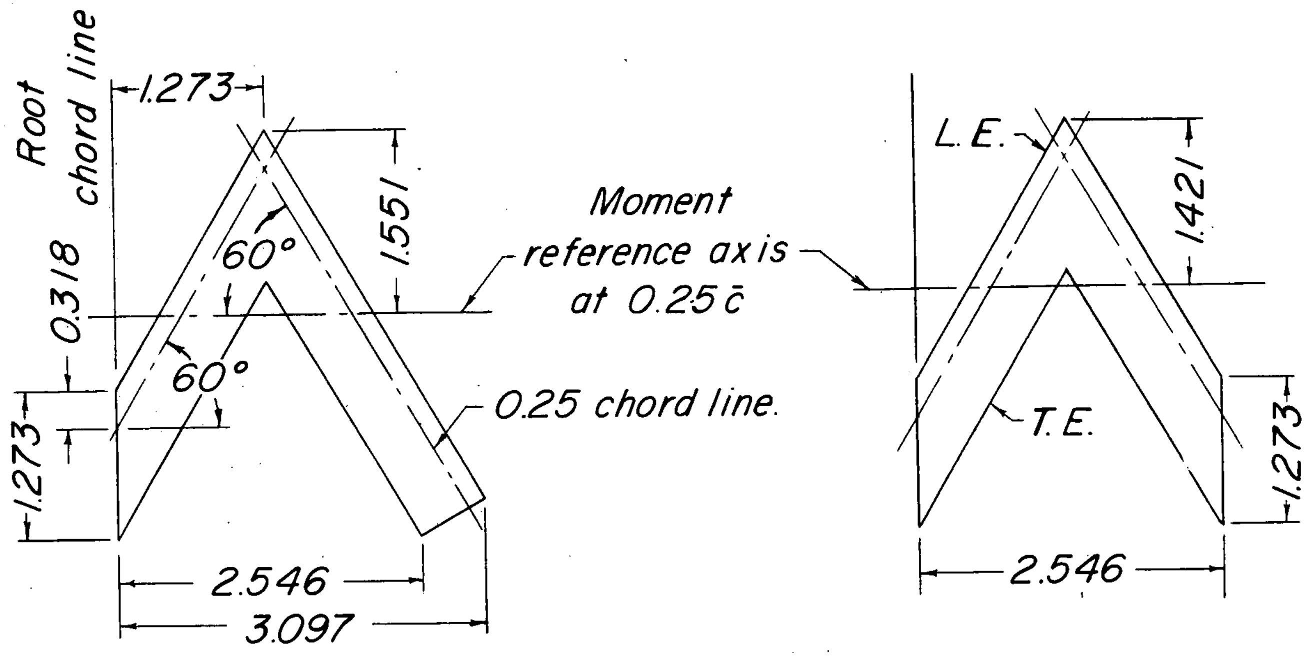
4. Katz, Ellis, Marley, Edward T., and Pepper, William B.: Flight Investigation at Mach Numbers From 0.8 to 1.4 To Determine the Zero-Lift Drag of Wings With "M" and "W" Plan Forms. NACA RM L50G31, 1950.

5. Kemp, William B., Jr., Goodson, Kenneth W., and Booth, Robert A.: Aerodynamic Characteristics at a Mach Number of 1.38 of Four Wings of Aspect Ratio 4 Having Quarter-Chord Sweep Angles of 0°, 35°, 45° and 60°. NACA RM L50G14, 1950.

TABLE I

SUMMARY OF RESULTS

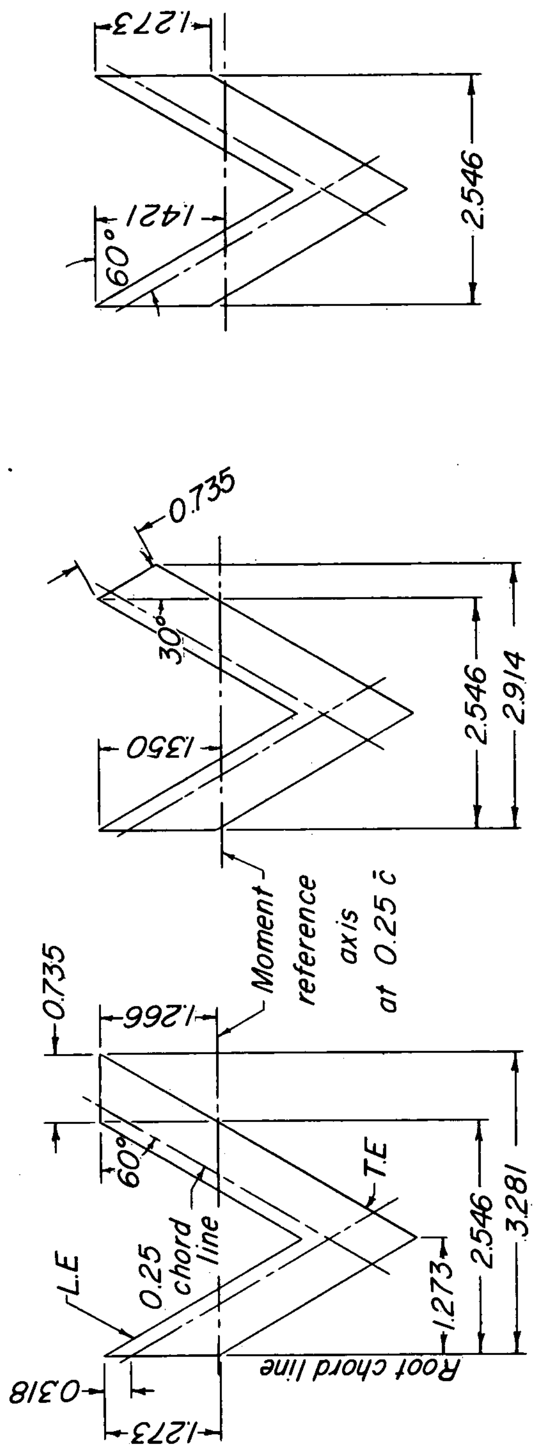
	M-wings		W-wings		
					
Smooth leading edge					
C_{L_α}	0.0460	0.0465	0.0330	0.0392	0.0380
$C_{D_{min}}$	0.0105	0.0115	0.0095	0.0120	0.0130
$(L/D)_{max}$	7.15	7.55	7.50	7.55	6.90
C_L for $(L/D)_{max}$ . .	0.190	0.215	0.150	0.175	0.180
$\Delta C_D/C_L^2$	0.420	0.366	0.482	0.373	0.376
$1/C_{L_\alpha}$, radians . . .	0.380	0.376	0.529	0.445	0.460
y_{cp}	0.498	0.455	0.464	0.447	0.446
y_{ca}	0.500	0.456	0.500	0.469	0.446
Rough leading edge					
C_{L_α}	0.0450	0.0473	0.0315	0.0360	0.0370
$\Delta C_D/C_L^2$	0.390	0.371	0.518	0.402	0.423
$1/C_{L_\alpha}$, radians . . .	0.388	0.369	0.554	0.485	0.472
y_{cp}	0.491	0.487	0.473	0.452	0.451
y_{ca}	0.500	0.456	0.500	0.469	0.446
$\partial C_m/\partial C_L$	-0.102	-0.169	-0.249	-0.175	-0.165



Tabulated wing data		
Aspect ratio	5.34	4.00
Mean aerodynamic chord	1.233 in.	1.273 in.
Area (twice semispan)	0.0499 sq. ft.	0.0450 sq. ft.
Airfoil section parallel to free stream	NACA 65A006	NACA 65A006

(a) M-wings.

Figure 1.- Dimensions of test models.



Tabulated wing data			
Aspect ratio	5.81	4.89	4.00
Mean aerodynamic chord	1.220 in.	1.246 in.	1.273 in.
Area (twice semispan)	0.0514 sq. ft.	0.0483 sq. ft.	0.0450 sq. ft.
Airfoil section parallel to free stream	NACA 65A006	NACA 65A006	NACA 65A006

(b) W-wings.

Figure 1.- Concluded.

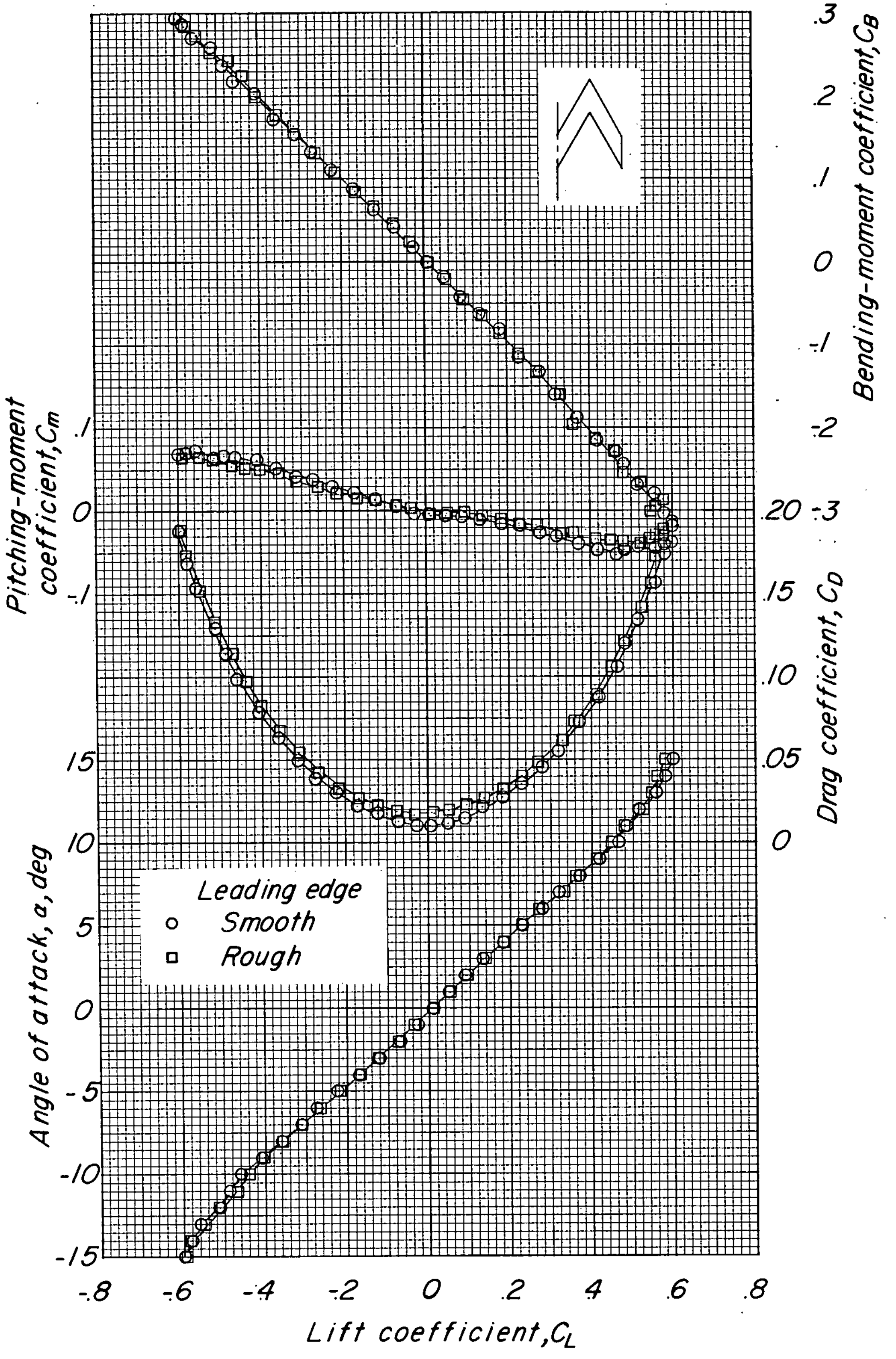


Figure 2.- Aerodynamic characteristics of M-wing with streamwise tip.

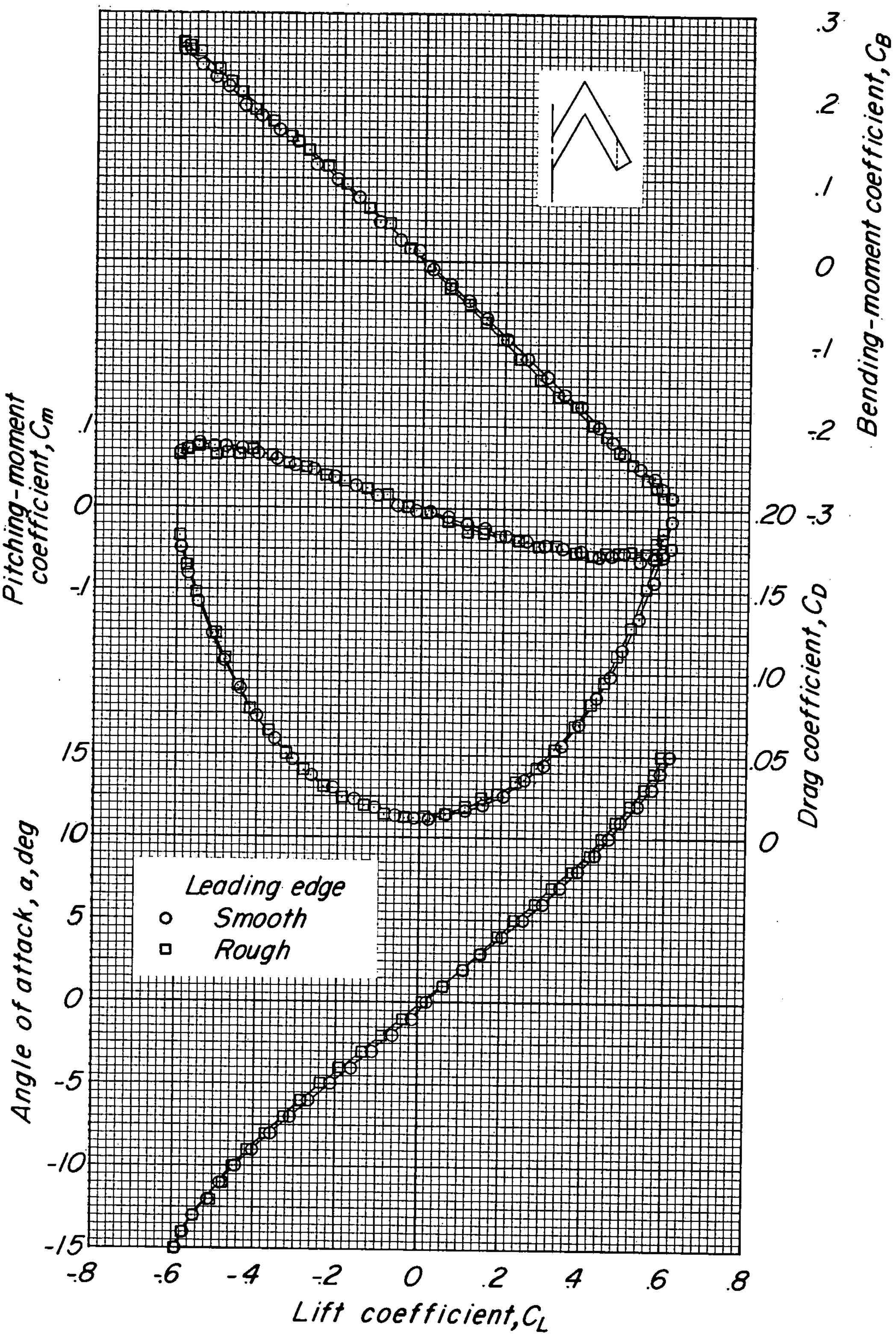


Figure 3.- Aerodynamic characteristics of M-wing with tip extension.

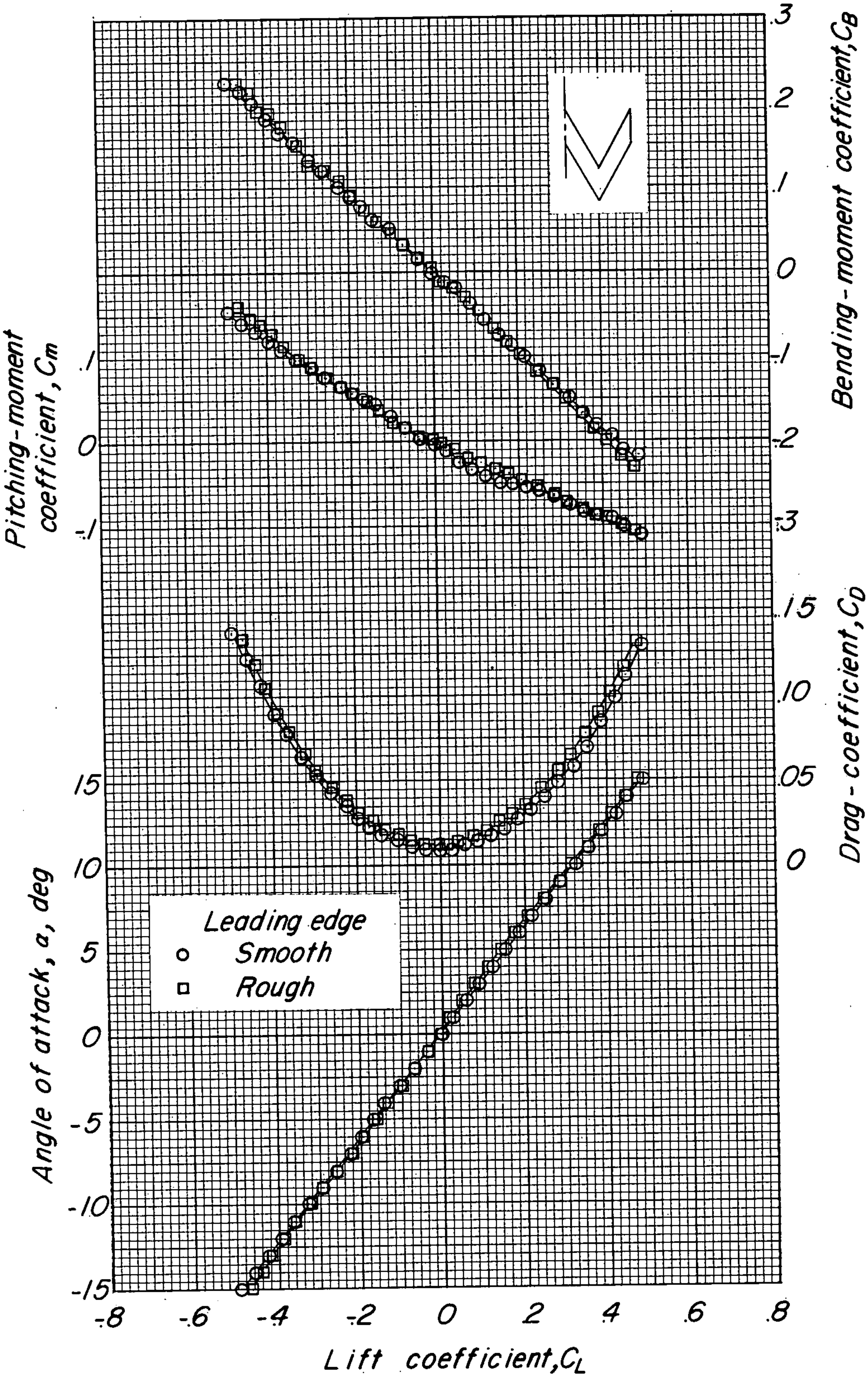


Figure 4.- Aerodynamic characteristics of W-wing with streamwise tip.

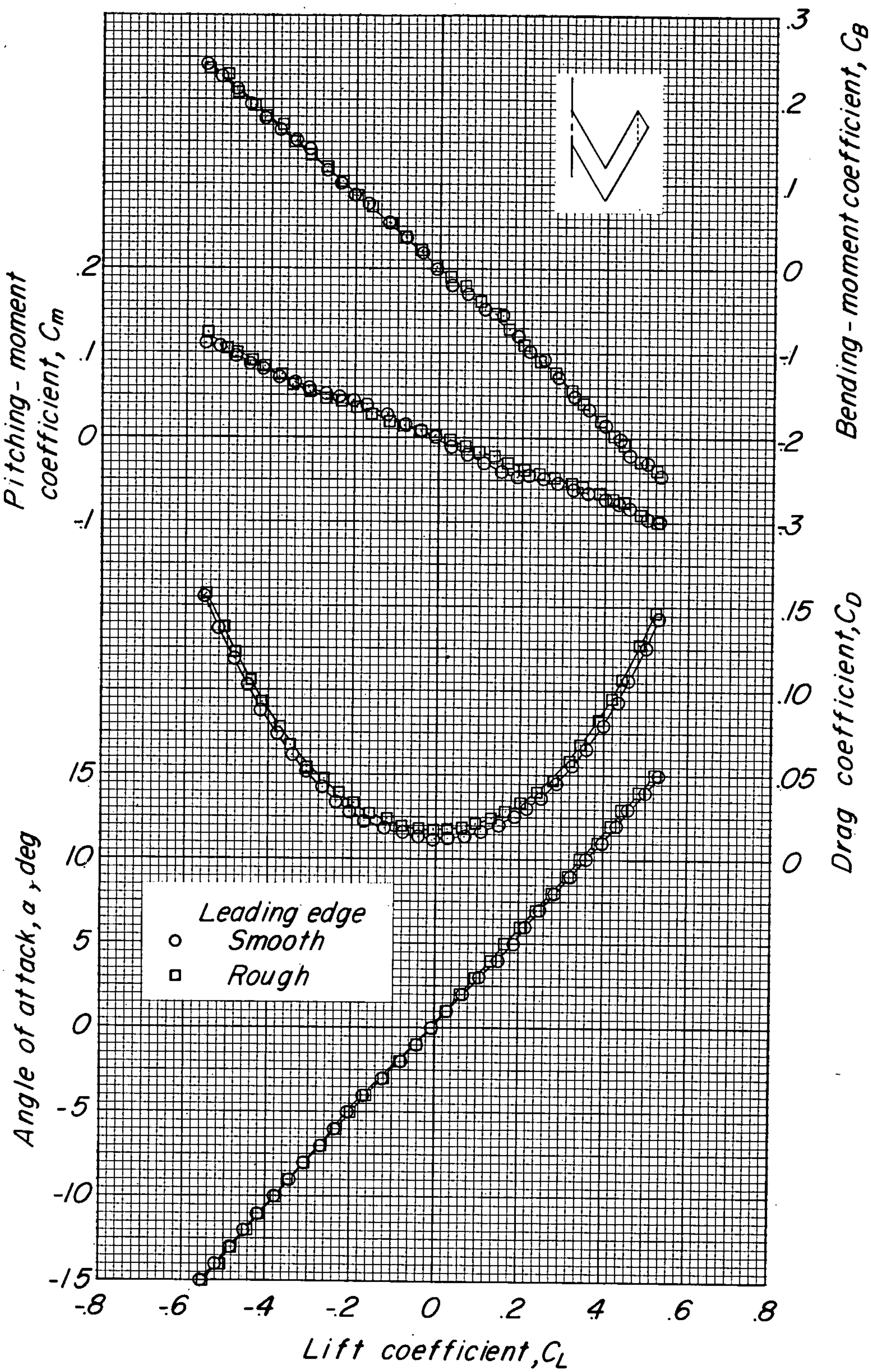


Figure 5.- Aerodynamic characteristics of W-wing with small tip extension.

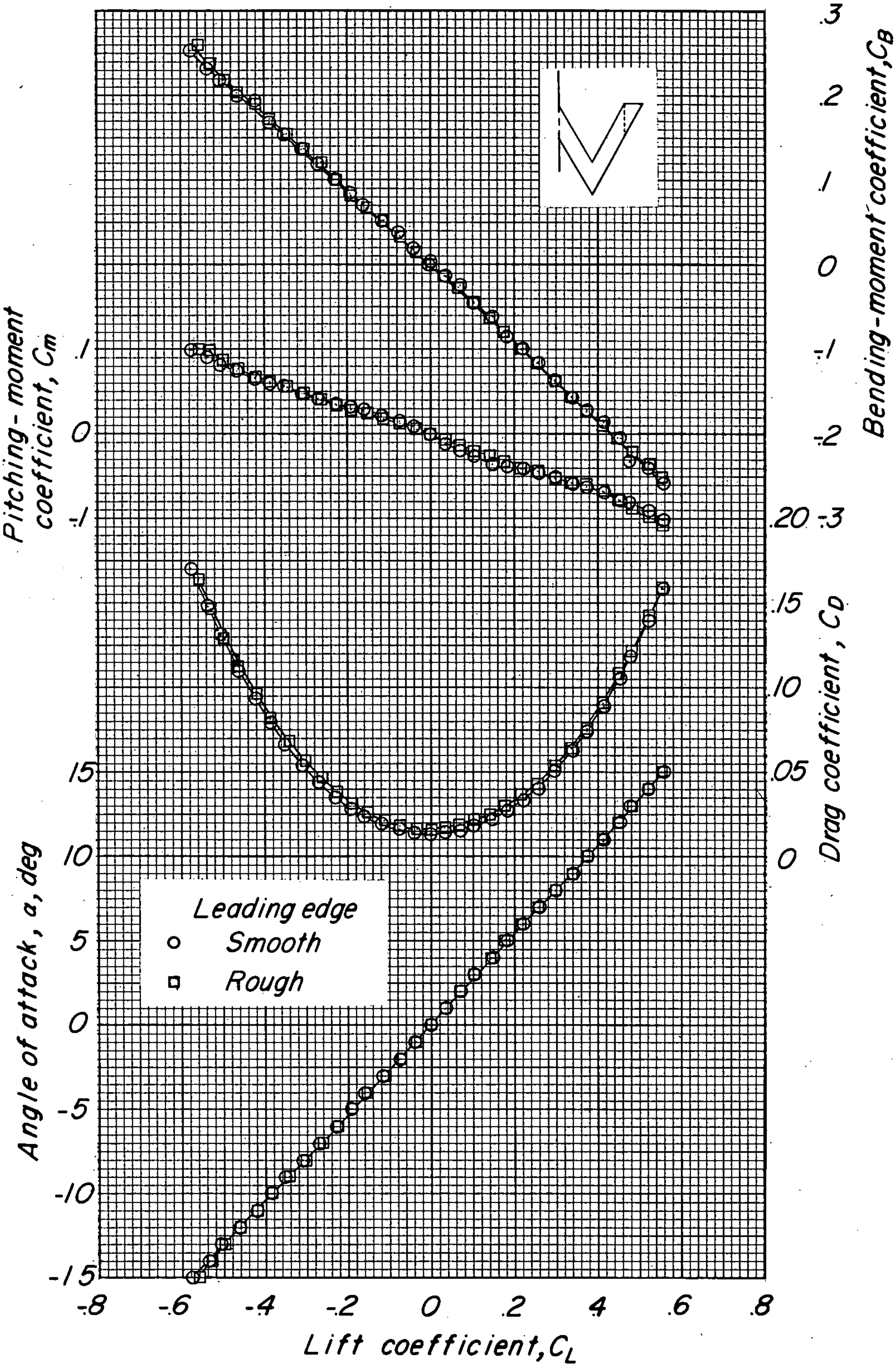


Figure 6.- Aerodynamic characteristics of W-wing with large tip extension.

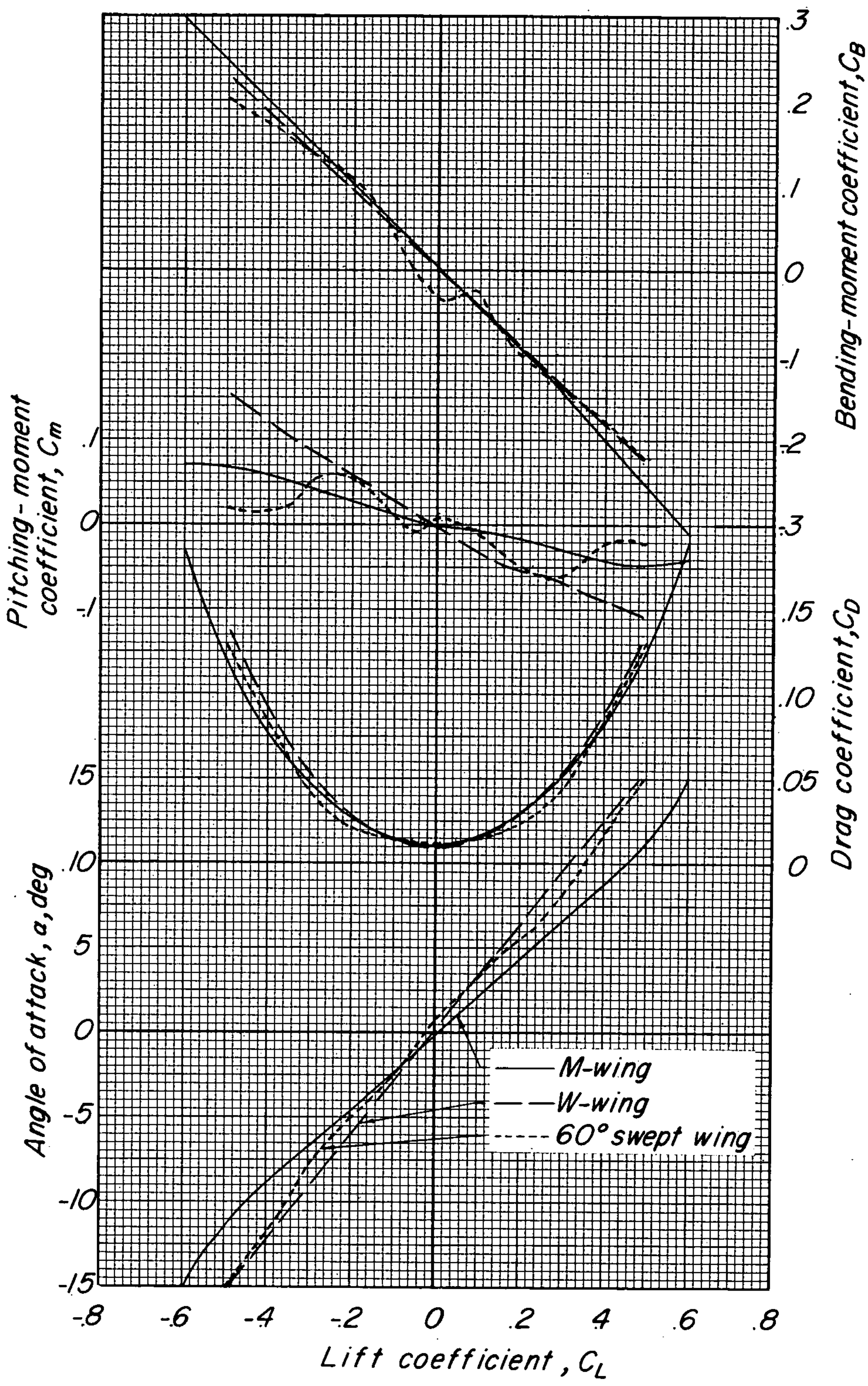


Figure 7.- Comparison of aerodynamic characteristics of 60° sweptback wing and M- and W-wings with streamwise tips and smooth leading edge. All data uncorrected for flexibility.

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